Course guides
820450 - CMAM - Computational Mechanics Applications

Last modified: 25/07/2016

Unit in charge: Barcelona East School of Engineering
Teaching unit: 737 - RMEE - Department of Strength of Materials and Structural Engineering.

Degree: BACHELOR'S DEGREE IN MECHANICAL ENGINEERING (Syllabus 2009). (Optional subject).

Academic year: 2016 **ECTS Credits:** 6.0 **Languages:** English

LECTURER

Coordinating lecturer: DANIEL DI CAPUA

Others: DANIEL DI CAPUA - JOSEP MARIA CARBONELL PUIGBO

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Transversal:
1. THIRD LANGUAGE. Learning a third language, preferably English, to a degree of oral and written fluency that fits in with the future needs of the graduates of each course.
2. TEAMWORK - Level 3. Managing and making work groups effective. Resolving possible conflicts, valuing working with others, assessing the effectiveness of a team and presenting the final results.

TEACHING METHODOLOGY

The course uses the narrative method by 50%, individual work 25%, and project-based learning by 25%.

LEARNING OBJECTIVES OF THE SUBJECT

The course is particularly addressed to those interested in the analysis and design of solids and structures, understood here in a broad sense. The Finite Elements Method (FEM) concepts explained in the course are therefore applicable to the analysis of structures in civil engineering constructions, buildings and historical constructions, mechanical components and structural parts in automotive, naval and aerospace engineering, among many other applications.
The following general objectives of this course can be considered:

1. Introduction to the basic concepts of the resolution problems of solid mechanics with the FEM.
2. Acquisition of a specific vocabulary of FEM.
3. Ability to read, correctly interpret and understand texts, figures and tables in technical literature related to FEM.
4. Ability to handle basic FEM software.
5. Acquire basic knowledge of literature and ability to perform literature searches relating to the scope of the FEM.
6. Knowledge of sources of information, institutional and private, related to the FEM.
7. Capacity for independent learning issues within the scope of the FEM.

STUDY LOAD

Type	Hours	Percentage
Hours large group	30,0	20.00
Guided activities	15,0	10.00
Self study	90,0	60.00
Hours small group	15,0	10.00

Total learning time: 150 h

CONTENTS

TOPIC 1: INTRODUCTION TO THE FINITE ELEMENT METHOD FOR STRUCTURAL ANALYSIS

Description:
What is the Finite Element Method? Analytical and numerical methods. What is a finite element? Structural modelling and fem analysis. Discrete systems. Bar structures. Direct assembly of the global stiffness matrix. Derivation of the matrix equilibrium equations for the bar using the principle of virtual work. Derivation of the bar equilibrium equations via the minimum total potential energy principle. Plane frameworks. Treatment of prescribed displacements and computation of reactions. Introduction to the finite element method for structural analysis. The value of finite element computations for structural design and verification.

Specific objectives:
Know the first concepts of structural and computational models. Know the basic steps of matrix analysis of bar structures. Be able to understand the relation betwen FEM and the methodology of matrix structural analysis. Know and be able to understand clearly the concept of splitting a structure in different elements, the equilibrium of the individual elements and the assembly of the global equilibrium equations of the structure from the contributions of the different elements.

Related activities:
1. Generating geometries in the GiD program. Part 1

TOPIC 2: FINITE ELEMENTS FOR AXIALLY LOADED RODS

Description:
Introduction. Axially loaded rod. Axially loaded rod of constant cross section. Discretization in one linear rod element. Derivation of the discretized equations from the global displacement interpolation field. Axially loaded rod of constant cross section. Discretization in two linear rod elements. Generalization of the solution with n linear rod elements. Extrapolation of the solution from two different meshes. Matrix formulation of the element equations. Summary of the steps for the analysis of a structure using the fem.

Specific objectives:
Know and be able to understand the FEM formulation for the analysis of simple axially loaded bars using one-dimensional (1D) bar elements. Know and be able to apply the key ingredients of the FEM, such as discretization, interpolation, shape functions, numerical integration of the stiffness matrix and the equivalent nodal force vector for the element.

Related activities:
2. Generating geometries in the GiD program. Part 2

TOPIC 3: ADVANCED ROD ELEMENTS AND REQUIREMENTS FOR THE NUMERICAL SOLUTION

Description:
Introduction. One dimensional c0 elements. Lagrange elements. Isoparametric formulation and numerical integration. Numerical integration. Steps for the computation of matrices and vectors for an isoparametric rod element. Basic organization of a finite element program. Selection of element type. Requirements for convergence of the solution. Assessment of convergence requirements. Other requirements for the finite element approximationthe patch test. Some remarks on the compatibility and equilibrium of the solution. Convergence requirements for isoparametric elements. Error types in the finite element solution. Concluding remarks.

Specific objectives:
Know and be able to apply other general concepts such as the patch test, the conditions for convergence of the FE solution, the types of errors, numerical integration.

Related activities:
3. Generating meshes in the GiD program. Part 2.
4. Generating meshes in the GiD program. Part 2.

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TOPIC 4: BIDIMENSIONAL SOLIDS

Description:
Introduction. Two dimensional elasticity theory. Finite element formulation. Three-noded triangular element. The four noded rectangular element. Performance of the 3-noded triangle and the 4-noded rectangle. Derivation of the shape functions for co two dimensional elements. Lagrange rectangular elements. Serendipity rectangular elements. Shape functions for c0 continuous triangular elements. Analytic computation of integrals over Rectangles and straight-sided triangles. General performance of triangular and rectangular elements. Enhancement of 2d elasticity elements using drilling rotations. Isoparametric quadrilateral elements. Isoparametric triangular elements. Numerical integration in two dimensions. Numerical integration of the element matrices and vectors. Computer programming of K(e) and f (e). Optimal points for computing strains and stresses. Selection of the quadrature order. Performance of 2d isoparametric solid elements. The patch test for solid elements. Applications. Concluding remarks.

Specific objectives:
Know and be able to the basics concepts of structures under the assumption of 2D elasticity. Know and be able to apply the key ideas of the formulation of the 3-noded triangular element. Know the explicit form of the element stiffness matrix and the equivalent nodal force vector are given. Know the derivation of the shape functions for 2D solid elements of rectangular and triangular shape and different orders of approximation. Be able to understand that the resulting expressions for the shape functions are applicable to axisymmetric solid elements, as well as for many plate and shell elements. Know the formulation of 2D solid elements of arbitrary shape (i.e. irregular quadrilateral and triangular elements with straight or curved sides) using the isoparametric formulation and numerical integration. Know and be able to understand the essential ideas of the organization of a general FEM computer program applicable to elements of different shape and approximation order.

Related activities:
5. 2D Solids examples. Part 1.
6. 2D Solids examples. Part 2.
7. 2D Solids examples. Part 3.

TOPIC 5: AXISYMMETRIC SOLIDS

Description:
Introduction. Finite element formulation. Three-noded axisymmetric triangle. Other rectangular or straight-sided triangular axisymmetric solid elements. Isoparametric axisymmetric solid elements. Analogies between the finite element formulations for plane elasticity and axisymmetric solids. Examples of application. Concluding remarks.

Specific objectives:
Be able to notice of the use is made of the concepts explained in the previous two chapters, such as the derivation of the element shape functions, the isoparametric formulation and numerical integration. Discuss several applications of axisymmetric solids and structures.

Related activities:
8. Axisymmetric Solids examples. Part 1.
9. Axisymmetric Solids examples. Part 2.

TOPIC 6: THREE DIMENSIONAL SOLIDS

Description:
Introduction. Basic theory. Finite element formulation. The four-Noded tetrahedron. Other 3d solid elements. Right prisms. Straight-edged tetrahedra. Computation of element integrals. 3d isoparametric elements. Numerical integration. Numerical integration of element matrices. Performance of 3d solid elements. Examples. Concluding remarks.

Specific objectives:
Know and be able to understand the formulation 3D solid elements of tetrahedral and hexahedral shapes. Be able to notice that 3D solid elements allow the FEM analysis of any structure. Know the details of the derivation of the stiffness matrix and the equivalent nodal force vector for the simple 4-noded tetrahedral element. Know and be able to apply the formulation of higher order 3D solid elements is explained using the isoparametric formulation and numerical integration. Discuss several applications of 3D solid elements to a wide range of structures such as dams, buildings, historical constructions and mechanical parts.

Related activities:
10. 3D Solids examples. Part 1.
11. 3D Solids examples. Part 2.
12. 3D Solids examples. Part 3.

TOPIC 7: MISCELLANEOUS

Description:
Introduction. Boundary conditions in inclined supports. Joining dissimilar elements. Displacement constraints. Nodal condensation and substructures. Structural symmetry. Structures on elastic foundation. Computation of nodal stresses. Error estimation and mesh adaptivity.

Specific objectives:
Know and be able to understand several topics of general interest for FEM analysis. These include the treatment of inclined supports, the blending of elements of different types, the study of structures on elastic foundations, the use of substructuring techniques, the procedures for applying constraints on the nodal displacements, the computation of stresses at the nodes and the key concepts of error estimation and adaptive mesh refinement strategies.

Related activities:
13. Working in the final project. Part 1
14. Working in the final project. Part 2

GRADING SYSTEM

Mid-term exam: 30%
Practices: 35%
Final exam: 35%

BIBLIOGRAPHY

Basic:
- Oñate, E. Structural analysis with the finite element method : linear statics, vol. 1, Basis and solids. Barcelona: CIMNE; [London] : Springer, 2009. ISBN 9781402087325.

Complementary:
- Bathe, K. J. Finite element procedures. [s.l.]: l'autor, 2006. ISBN 9780979004902.